

WE CLAIM:

[cl 1] A method for controlling downhole operation of a multi-cycle dump valve mechanism of a straddle packer tool within a well casing, said multi-cycle dump valve mechanism having a valve operating mandrel movable within a housing and supporting a dump valve element for open and closed positioning relative to a valve seat of said housing, an indexing mechanism controlling closing movement of said valve operating mandrel and an energy storage system, said method comprising:

positioning the straddle packer tool and multi-cycle dump valve mechanism at a desired location within a well casing and with said valve operating mandrel of said dump valve mechanism at a starting position with said valve element open;

causing flow responsive conditioning of said indexing mechanism for closing movement of said valve operating mandrel and said dump valve element;

causing flow responsive dump valve closing movement of said valve operating mandrel and storing energy in said energy storage system during said flow responsive valve closing movement

with said dump valve element closed with respect to said valve seat, causing the flow of fluid through the straddle packer tool and accomplishing well treatment;

upon completion of well treatment, causing stored energy return of said valve operating mandrel to an intermediate valve open position causing dumping of fluid through said dump valve mechanism into the well casing; and

with said energy storage system returning said valve operating mandrel to said starting position.

[cl 2] The method of claim 1, wherein a power piston having a ratcheting collet mechanism is disposed in releasable force transferring relation with said valve operating mandrel and said power piston is disposed in energy transferring relation with said energy storage system, said method comprising:

during flow responsive movement of said valve operating mandrel in the valve closing direction engaging said ratcheting collet mechanism with said valve operating mandrel; transferring energy storing force from said valve operating mandrel and said power piston to said energy storage system; and

utilizing said stored energy for causing valve opening movement of said valve operating mandrel against high pressure gradients and returning said valve operating mandrel to said starting position.

[cl 3] The method of claim 1, wherein said indexing mechanism is defined by an indexing sub of said valve operating mandrel, said indexing sub having an indexing slot and an indexing lug and an indexing sleeve being mounted for rotation about said indexing slot and having a tracking element engaged within said indexing slot, said indexing sleeve defining a lug movement slot, said step of causing flow responsive conditioning of said indexing mechanism comprising:

causing flow responsive linear movement of said valve operating mandrel in a valve closing direction from said starting position to an indexing position; and

returning said valve operating mandrel from said indexing position and causing said indexing slot to rotate said indexing sleeve to a position aligning said lug movement slot with said indexing lug.

[cl 4] The method of claim 3, comprising:

causing flow responsive linear movement of said valve operating mandrel in a valve closing direction and moving said indexing lug through said lug movement slot of said indexing sleeve and positioning said dump valve element in valve closing relation with said valve seat.

[cl 5] The method of claim 1, wherein said indexing mechanism is defined by an indexing sub of said valve operating mandrel, said indexing sub having an indexing slot and an indexing lug and an indexing sleeve being mounted for rotation about said indexing slot and having a tracking element engaged within said indexing slot, said indexing sleeve defining a lug movement slot, said method comprising:

during flow responsive valve movement of said valve operating mandrel in the valve closing direction engaging said indexing sleeve with said indexing lug and restraining complete closure of said dump valve mechanism.

[cl 6] The method of claim 5, comprising:

indexing said dump valve mechanism for valve closure by causing rotation of said indexing sleeve to a position aligning said lug movement slot with said indexing lug and causing flow responsive movement of said valve operating mandrel to a position locating said dump valve element in seated relation with said valve seat.

[cl 7] The method of claim 2, wherein said energy storage system having a high load energy storage device having sufficient force transmitting capacity for opening said dump valve mechanism against large hydrostatic gradients and a lower load energy storage device

having sufficient force transmitting capacity for returning said valve operating mandrel to said starting position, said step of storing energy in said energy storage system comprising:

establishing force transmitting engagement of said ratcheting collet mechanism with said valve operating mandrel;

during flow responsive movement of said valve operating mandrel toward valve closing position applying fluid pressure to said power piston and storing energy in said lower load energy storage device;

maintaining fluid pressure on said power piston during well treatment;

decreasing fluid pressure on said power piston sufficiently to permit opening of said dump valve by said first energy storage device; and

further decreasing fluid pressure on said power piston, permitting movement of said valve operating mandrel toward said starting position by said second energy storage device.

[cl 8] The method of claim 2, wherein said ratcheting collet mechanism comprises a tubular collet sub being connected in said valve operating mandrel and defining buttress threads and said power piston having a plurality of collet fingers each having buttress threads disposed for ratcheting engagement with said buttress threads of said tubular collet sub, said method comprising:

causing pressure responsive downward movement of said power piston, with flow responsive movement of said valve operating mandrel being restrained by said indexing sleeve, causing ratcheting of said buttress threads of said plurality of collet fingers over said buttress threads of said tubular collet sub; and

causing relative pressure responsive positioning of said power piston and said valve operating mandrel and maintaining valve opening force transmitting engagement of said

power piston and said valve operating mandrel during said relative pressure responsive positioning.

[cl 9] A method for controlling downhole operation of a multi-cycle dump valve mechanism of a straddle packer tool, said multi-cycle dump valve mechanism having a valve operating mandrel movable within a housing and supporting a valve element for open and closed positioning relative to a valve seat of said housing, an indexing mechanism controlling closing movement of said valve operating mandrel, a power piston having a ratcheting collet mechanism and an energy storage system in force transferring relation with said power piston, said method comprising:

positioning the straddle packer tool and dump valve mechanism at a desired location within a well casing and with said valve operating mandrel of said dump valve mechanism at a starting position with said valve element open;

causing a flow responsive linear movement of said valve operating mandrel to an intermediate position and storing energy within said energy storage system;

energizing said ratcheting collet mechanism and releasably interconnecting said power piston with said valve operating mandrel;

causing further flow responsive closing movement of said valve operating mandrel to an intermediate position and with said collet mechanism transferring force from said valve operating mandrel to said power piston;

increasing flow responsive force on said valve operating mandrel and moving said valve operating mandrel to a valve closed position and causing said power piston to further load said energy storage system;

with said dump valve closed causing the flow of fluid through the straddle packer tool and accomplishing well treatment;

upon completion of well treatment, reducing application of fluid pressure to said dump valve mechanism and causing stored energy return of said dump valve mechanism to an intermediate valve open position causing dumping of fluid through said dump valve mechanism into the well casing; and

with said energy storage system and said ratcheting collet mechanism returning said valve operating mandrel to said starting position.

[cl 10] The method of claim 9, wherein the energy storage system comprises a low load energy storage device and a higher load energy storage device, said method comprising:

causing fluid flow responsive development of a condition activating said low load energy storage device and moving the dump valve mechanism toward the closed position thereof and storing sufficient energy in said low load energy storage device for returning said valve operating mandrel to said starting position; and

increasing fluid pressure within said dump valve mechanism to a level activating said higher load energy storage device and storing sufficient energy for overcoming any high pressure gradient and causing initial opening movement of said dump valve mechanism from said closed position.

[cl 11] The method of claim 9, wherein the first energy storage device is at least one spring having a predetermined load capacity and the second energy storage device is at least one spring having a load capacity exceeding the predetermined load capacity and a moveable mandrel is disposed in force transmitting and receiving relation with the springs of the first and second energy storage devices, said method comprising:

after predetermined flow responsive valve closing movement of said valve operating mandrel establishing driving engagement of said power piston member with said collet mechanism and applying sufficient pressure to the area of said power piston for moving said valve operating mandrel to valve closing position and storing sufficient energy in said energy storage system overcoming the force of any high pressure gradient on said valve element and causing valve opening movement of said valve operating mandrel.

[cl 12] The method of claim 9, wherein the dump valve mechanism has a valve operating mandrel supporting a valve element of said dump valve and a power piston member in force transmitting engagement with said energy storage system and a collet mechanism releasably connecting said valve operating mandrel and said power piston member, said method comprising:

after predetermined flow responsive valve closing movement of said valve operating mandrel establishing driving engagement of said power piston member with said collet mechanism and applying sufficient fluid pressure to said power piston and selectively moving said valve operating mandrel by force of said power piston member to the valve closed position and storing sufficient energy in said energy storage system for causing opening movement of said valve operating mandrel.

[cl 13] The method of claim 12, wherein a ratcheting collet mechanism establishes driving connection between said valve operating mandrel and said power piston member, said method comprising:

engaging said ratcheting collet mechanism with said valve operating mandrel during an initial portion of flow responsive valve closing movement of said valve operating mandrel;

causing pressure responsive ratcheting of said ratcheting collet mechanism and imparting power piston force to said energy storage system responsive to differential pressure; and

releasing force from said storage system to said valve operating mandrel for moving said valve operating mandrel toward the open position thereof.

[cl 14] The method of claim 13, wherein an indexing mechanism is operative for position control of said valve operating mandrel and said energy storage system comprises a low load energy storage device having a load capacity causing returning movement of said valve operating mandrel and operating said indexing mechanism and a higher load energy storage device having a load capacity for causing opening movement of said valve operating mandrel under conditions of large pressure gradients, said method comprising:

during an initial portion of the closing movement of said valve operating mandrel from the open position thereof storing energy in said low load energy storage device and positioning said valve operating mandrel at an intermediate position with the dump valve mechanism open, and

with said indexing mechanism preventing closure of said dump valve mechanism by flow responsive force acting on said valve operating mandrel.

[cl 15] The method of claim 13, comprising:

positioning said indexing mechanism for dump valve closure;

applying flow responsive force to said valve operating mandrel to close said dump valve; and

during valve closing movement of said valve operating mandrel causing pressure responsive power piston force induced energy storage in at least one of said energy storage devices.

[cl 16] A multi-cycle dump valve mechanism for a straddle packer tool, comprising:

a valve tool housing being connected in fluid communicating relation with a straddle packer tool and having a valve seat and defining a discharge opening;

a valve actuating mandrel being disposed for valve opening and closing movement within said valve tool housing and having a valve element being moveable to open and closed positions relative to said valve seat, said tubular mandrel having a flow passage defining a restriction;

an indexing mechanism having movement controlling engagement with said valve actuating mandrel and being moveable within said valve tool housing and controlling positioning of said valve actuating mandrel at a valve open position, an intermediate position preventing valve closure and a valve closed position; and

an energy storage system within said valve tool housing and having valve opening force applying relation with said valve actuating mandrel, said energy storage system being at least partially loaded responsive to differential pressure induced force developed by flow through said restriction.

[cl 17] The multi-cycle dump valve mechanism of claim 16, comprising:

a tubular indexing sub being fixed to said valve actuating mandrel and defining an indexing slot;

a position control lug being fixed to said tubular indexing sub; and

an indexing member being mounted for rotation within said valve tool housing and having a slot tracking element being disposed for tracking movement within said indexing slot, said indexing member having a stop shoulder being engaged by said position control lug to establish said intermediate position of said valve actuating mandrel and an internal slot

being positionable for receiving said position control lug and permitting downward movement of said valve actuating mandrel to said valve closed position.

[cl 18] The multi-cycle dump valve mechanism of claim 17, comprising:

said indexing slot being a J-type indexing slot interacting with said slot tracking element and rotating said indexing sleeve to a position aligning said internal slot of said indexing sleeve with said position control lug and permitting flow responsive closing movement of said valve actuating mandrel.

[cl 19] The multi-cycle dump valve mechanism of claim 16 wherein said energy storage system comprises:

a power piston interposed between and in sealing relation with said valve tool housing and said valve actuating mandrel and being moveable responsive to said differential pressure; and

at least one energy storage device having force transmitting relation with said power piston and said valve tool housing and urging said power piston in a direction causing opening movement of said valve actuating mandrel, said at least one energy storage device being loaded by force of said power piston.

[cl 20] The multi-cycle dump valve mechanism of claim 16 wherein said at least one energy storage device comprises:

a low load energy storage device having a predetermined load capacity sufficient for actuation of said indexing mechanism and a higher load energy storage device having a load capacity exceeding said predetermined load capacity and providing power for valve opening movement of said valve actuating mandrel against high pressure gradients.

[cl 21] The multi-cycle dump valve mechanism of claim 20, comprising:

said low load energy storage device being a coil spring;

said higher load energy storage device being a spring stack having a plurality of disk spring elements; and

a spring stop member limiting compression of said coil spring.

[cl 22] The multi-cycle dump valve mechanism of claim 16 wherein said energy storage system comprises:

a power piston interposed between and in sealing relation with said valve tool housing and said valve actuating mandrel and being moveable responsive to said differential pressure;

at least one energy storage device having force transmitting relation with said power piston and said valve tool housing and urging said power piston in a direction causing opening movement of said valve actuating mandrel, said at least one energy storage device being loaded by force of said power piston; and

a collet mechanism releasably connecting said valve operating mandrel and said power piston.

[cl 23] The multi-cycle dump valve mechanism of claim 22 wherein said collet mechanism comprises:

a tubular collet member being fixed to said valve actuating mandrel and defining a threaded section; and

a plurality of collet fingers extending from said power piston and each defining a thread section, said plurality of collet fingers each having a release position with said thread sections thereof disposed in non-engaging relation with said threaded section and an engaging position with said thread sections thereof disposed in engaging relation with said threaded section.

[cl 24] The multi-cycle dump valve mechanism of claim 22, comprising:

a collet release member being located within said valve tool housing and releasing said collet connection of said valve operating mandrel and said power piston upon movement of said collet to a release position within said valve tool housing.

[cl 25] The multi-cycle dump valve mechanism of claim 23, comprising:

the threads of said threaded section of said tubular collet member and said thread sections of said plurality of collet fingers being ratcheting buttress threads permitting closing movement of said valve actuating mandrel and concurrent downward movement of said power piston until said valve operating mandrel reaches a position closing said dump valve mechanism; and

after closing of said dump valve mechanism and during further pressure actuated downward movement of said power piston said thread sections of said plurality of collet fingers ratcheting over said threaded section of said tubular collet member and establishing predetermined collet positioning causing opening movement of said valve actuating mandrel and said dump valve element by said at least one energy storage device upon decrease of fluid pressure acting on said power piston.

[cl 26] The multi-cycle dump valve mechanism of claim 23, comprising:

said collet release member having a tapered release portion separating said thread sections of said plurality of collet fingers from said threaded section of said tubular collet member when engaged by said plurality of collet fingers.

[cl 27] The multi-cycle dump valve mechanism of claim 23, comprising:

an annular collet control surface being located within said valve tool housing;

said plurality of collet fingers being moveable within said collet control surface and having collet control projections engaging said collet control surface and securing said thread

sections of said plurality of collet fingers in engaging relation with said threaded section of said tubular collet member.

[cl 28] The multi-cycle dump valve mechanism of claim 22, comprising:

said thread sections of said plurality of collet fingers being located intermediate the length of each of said plurality of collet fingers and said plurality of collet fingers being positioned as bow spring collet finger members and as cantilevered collet finger members during relative movement of said plurality of collet fingers and said tubular collet member.

[cl 29] The multi-cycle dump valve mechanism of claim 16, comprising:

said valve seat being moveable to a position opening said dump valve in the event a predetermined maximum pressure is exceeded with said dump valve mechanism.

[cl 30] A flow responsive multi-cycle dump valve mechanism for a straddle packer tool, comprising:

a dump valve housing being connected in fluid communicating relation with a straddle packer tool and having a valve seat and defining a fluid discharge opening;

a valve operating mandrel being moveable with said dump valve housing and being disposed for positioning at a starting position and having valve opening and closing movement within said valve tool housing and having a valve element being moveable to open and closed positions relative to said valve seat, said tubular valve operating mandrel having a flow passage defining at least one fluid flow restriction developing a pressure differential and a resultant force acting on said valve operating mandrel in the valve closing direction responsive to fluid flow;

an indexing mechanism having movement controlling relation with said valve actuating mandrel and controlling positioning of said valve actuating mandrel at a valve open position, an intermediate position preventing valve closure and a valve closed position;

a low load energy storage device within said valve tool housing having a load capacity causing return of said valve operating mandrel to said starting position;

a higher load energy storage device within said valve tool housing having a load capacity overcoming the restraining force of high pressure gradients and causing opening movement of said valve actuating mandrel from the closed position; and

a pressure responsive ratcheting power piston having releasable connection with said valve actuating mandrel and having force transferring relation with said low load and higher load energy storage devices and loading said higher load energy storage device by pressure induced force of said power piston, upon reduction of fluid pressure acting on said power piston said higher load energy storage device ensuring valve opening movement of said valve operating mandrel in the event of high pressure gradient and said low load energy storage device returning said valve operating mandrel to said starting position.